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Recent Progress in the Production of Error-Free Magnetic Computer Tape

J. C. CHAPMAN† AND W. W. WETZEL†

INTRODUCTION

SIGNAL DROPOUTS arising from magnetic tape are one cause of error in modern digital computers designed to use such tape as a long period storage medium. Noise pulses, which are of sufficient amplitude to act as spurious signals, form a second error source. Both dropouts and noise pulses are traceable to discontinuities in the magnetic coating.

During the past year extensive studies have been made of coating defects with the intention of minimizing their occurrence. We initially believed that if the discontinuities could be examined and classified there was hope for improving tapes by eliminating the defects at their source. This has been done and the practical results are gratifying.

This paper will explain briefly: (a) our findings concerning the physical causes of errors; (b) the reasons why errors arise from such physical defects; (c) steps taken to eliminate errors; and (d) a summary of our progress during 1953.

DETECTION OF ERRORS

The equipment used for dropout detection records square-wave pulses at a rate of 100 to the inch on seven tracks of a half-inch wide tape. The recorded tape is read back and if the signal for any pulse falls below 55 per cent of the normal maximum value, an error is recorded. At each error the tape is stopped automatically so its physical cause can be examined under a microscope.

Noise pulses which are counted as errors are located by saturating the tape continuously in one direction and stopping the tape during read-back when a noise peak exceeds 8 per cent of the normal maximum signal. Again, microscopic examination is used to find the physical cause of the noise pulse. Generally speaking, dropouts and noise pulses arise from the same physical causes and they have been grouped together under the general name of errors.

We have further classified errors as removable and nonremovable. Removable errors arise from loose particle contamination of the coated surface and may usually be cleaned off the tape with a soft brush. Nonremovable errors may be caused by oxide clumps or foreign particles which are embedded in the coating. Since removable errors may be eliminated through inspection they are at present considered to be unimportant. The data which follow will be confined to nonremovable errors.

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CAUSES OF ERRORS

Nonremovable signal dropouts may be caused by a lack of magnetic coating at the point where a pulse is supposed to be recorded, but the early experience of observers led to an explanation based on the more frequent occurrence of small inclusions (called "nodules") in the coating. Upon close inspection, these nodules could be classified as oxide clumps, acetate particles, embedded filter fibers, etc. Initially oxide clumps were the most frequent offenders.

Oxide clumps which protrude from the otherwise flat surface of the tape force the main body of the tape away from the recording and playback head gaps. During recording the effect of the presence of a nodule is to reduce the sharpness and the intensity of the recording field at the tape surface. On playback, where the rate of change of recorded flux is observed, the already reduced steepness of the flux front is observed from a distance which further reduces the rate of change of flux in the reproducing head. This combination results in a decrease in output which is called a dropout. If the dropout is sufficiently large it constitutes an error.

Noise errors similarly arise from discontinuities in the magnetic coating. The tape is magnetized to saturation longitudinally prior to read out in the noise test. The flux seen by the playback head under this condition of magnetization would be essentially zero for a perfect tape except for small variations in leakage flux from particle to particle of the oxide which causes the normal noise background. However, if a discontinuity in the coating occurs, which might result from a pin hole or the inclusion of a particle of nonmagnetic contaminate, magnetic poles will form on either edge of the gross discontinuity and the leakage flux will increase well above that due to the normal physical separation between oxide particles. A noise pulse also arises from nodules of oxide where excess magnetic material is present.

ELIMINATION OF ERRORS

As a preliminary step to elimination of errors from computing tapes, a study was made of the error types and their frequency of occurrence. It seemed obvious that if the causes of errors were known we would have a clue to the step in the tape-making process where they were introduced.

One typical example of oxide clumps is shown in Fig. 1. When such clumps are encountered during playback, they give rise to both dropouts and noise errors providing the clumps are of sufficient size. Fig. 2 shows a coating streak where absence of oxide caused

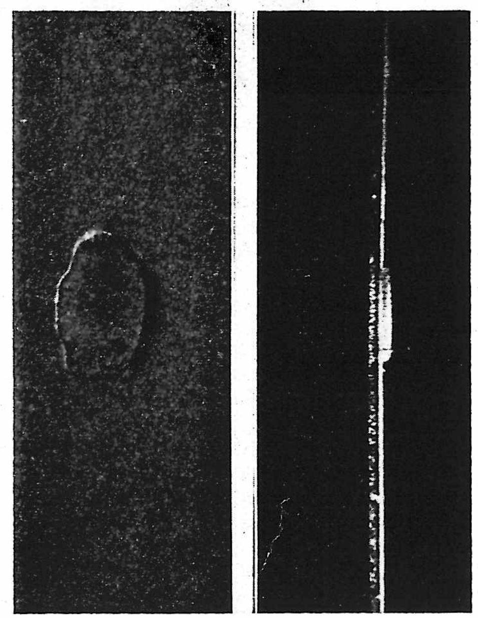

Fig. 1—Showing oxide flake embedded in coating and cross section of same (magnified 50 times).

both dropout and noise errors. Fig. 3 illustrates our findings in March, April, and May on the frequency and cause of nonremovable errors. Each sample represents 24 rolls of ½ inch×2,400 foot tape.

It will be seen that oxide flakes, tape distortion, and acetate particles were the predominate sources of error in March. A test run in April, 1953, was designed to eliminate oxide flakes, filter fibers, and tape distortion. Tape distortion arises primarily from creases in the tape due to faulty handling during the manufacturing process. The results of the initial experiments are shown in Fig. 3. We were successful in reducing to zero the number of errors from the three sources being studied.

Two runs were made in May in which special precautions were taken to eliminate acetate particles. We were apparently on the right track since both acetate and miscellaneous embedded particles were reduced in frequency of occurrence. The increase in oxide flakes to 1.5 errors on an average pointed out that our April observation was possibly based on too small a sample.

Since better than 50 per cent of the rolls during the last two trial runs were error-free, we decided to turn the process over to production. Fig. 4 shows the error count on production runs of relatively large samples. In order to compare the results with previous test runs, the bar graphs have been reduced to 24-roll equivalents. The runs illustrated total 664 rolls, ½ inch×2,400 feet.

In changing to production, our classification of errors was refined. Certain defects previously entered under miscellaneous particles were found to be attributable to imperfect backing. The acetate film used as tape back-

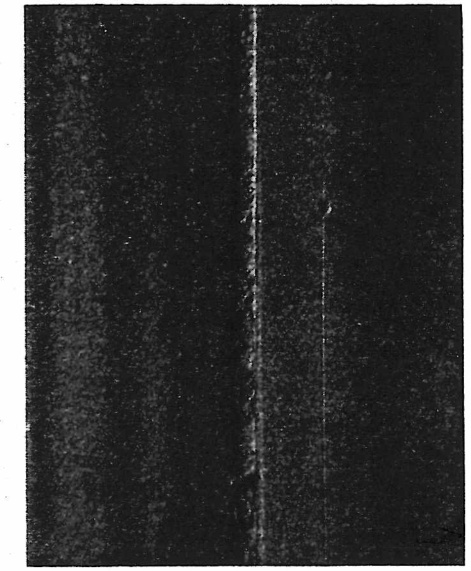

Fig. 2—Showing a streak in the magnetic coating which results in a deficiency of magnetic oxide along the streak (magnified 50 times).

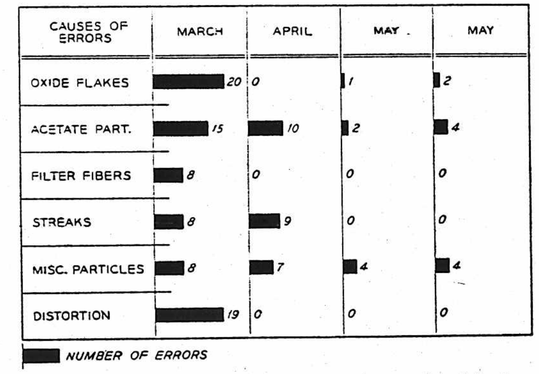

Fig. 3—Chart shows number and causes of errors found in four experimental lots of 24 rolls, each of ½-inch×2,400-foot computer tape. (In May experiments much improvement has been shown over March.)

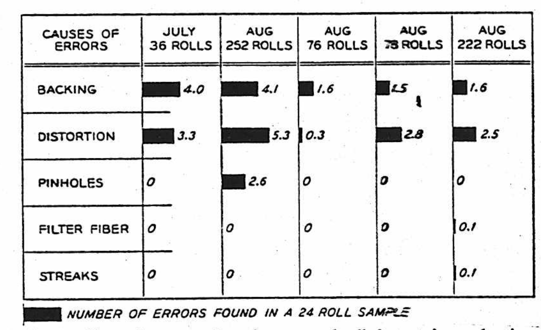

Fig. 4—Chart shows number of errors and rolls in certain production runs of computer tape. For comparison with Fig. 3 number of errors has been reduced to equivalent found in a 24-roll sample.

ing is cast on large diameter wheels having a polished surface. The film began to show tiny defects which were determined to be repetitive and which could therefore be attributed to a small dent in the surface of the wheel. The errors due to this source are listed as backing defects. Fig. 5 shows one such defect which occurred repeatedly in the acetate film.

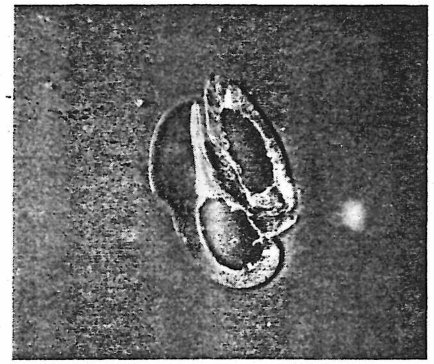

Fig. 5—This photomicrograph (magnified 25 times) illustrates appearance of a defect in acetate backing of magnetic tape. This irregularity is reflected in magnetic coating and gives rise to an error.

Tape distortion which arises from the permanent creases in tape backing occurs most frequently on the edge of the tape. The errors which arise from pin holes, from filter fibers, and from streaks, now appear to be purely random.

The bar graphs show that, through studies of errors and through efforts made to eliminate them, we have managed to reduce errors from 3.25 per roll in March, to 0.18 per roll in August.

Conclusion

To a tape manufacturer our studies show that if special precautions and techniques are used, production waste figures can be held within reasonable limits during runs of computing tape.

To the consumer of tapes it means that error-free tapes are available, providing each tape is individually checked by the manufacturer. Alternatively, if the consumer prefers to check each roll of untested computing tape, he may expect better than 75 per cent of the rolls to be error-free.

Discussion

F. Hawkins (David Taylor Model Basin): Is there any deterioration of the magnetic tape record with time? If so, what are the causes?

Mr. Wetzel: As far as we are able to determine the only deterioration of magnetic tape records comes from mechanical failure. Nicks in the edge of an acetate tape will cause tears. If the tape is run too often—I don't know how much that would be, 25,000 times or something like that—then the oxide will tend to abrade off. It is my opinion that the ultimate failure will be mechanical brought about through nicking of tape edges.

Mr. Hawkins: What is the frequency of errors to be expected on the best magnetic tape presently marketed by your company?

Mr. Wetzel: We are marketing No. 109, a so-called instrumentation tape. The data which I presented today gives the most recent figures we have on the frequency of errors in this tape. The figure which I gave in the summary is 0.18 errors per ½ inch tape, 2,400 feet long.

David Rutman (Rand Corporation): What width of recording track do you use in the tests?

Mr. Wetzel: The track width as I remember is 35-thousandths of an inch, give or take five mils for a poor memory.

Mr. Rutman: What is the size of the imperfections?

Mr. Wetzel: The size of the most frequent imperfections is of the order of 10-thousandths of an inch in diameter. The long streak I showed you on the board is something in the order of 1/10 of an inch long and five or ten mils wide.

Mr. Rutman: When will Mylar backing be available?

Mr. Wetzel: A member of the Dupont Corporation would have to answer that, really. Our best crystal ball, which is somewhat clouded in this prediction, says that Mylar backing for computer tape should be available some time in 1956. The Dupont people are quite certain that their plant will be in operation the latter part of next year, but I am afraid the perfection of film required for computer applications will not be attained for some additional time. If you recall, one of the most frequent imperfections in acetate backed tape which we observed in the last test runs are caused by dents in the casting wheel. These tiny defects will show up as errors. I think Mylar which now contains many inclusions is quite a way from the degree of perfection which acetate film has achieved after 25 to 30 years.

C. P. Bastuschek (Haller Raymond and Brown, Inc.): Has any check been made on the number of errors per reel of the aluminized tape?

Mr. Wetzel: Aluminized tape as it is generally delivered is used for static elimination. The aluminized tape is not the No. 109 computer tape quality, and I would guess—it would have to be a sheer guess—that something in the order of 10 errors per reel could be expected. It is not the computer quality material.

J. A. O'Brien (M.I.T.): Can you give information on Mylar tapes?

Mr. Wetzel: Mylar is a very intriguing material since it has relatively high tensile strength and very excellent tear resistance. It stands both higher and lower temperatures than acetate. The one reason that we do not recommend its use in computers is that the film at present has a good many defects in it. The tensile strength of acetate compared with Mylar is not too terrifically different. One-and-a-half mil acetate has the same strength as one mil Mylar. The superior tear resistance of Mylar is the outstanding quality you may expect under normal operating temperatures and humidities.

Reliability of Electrolytic Capacitors in Computers

MARK VanBUSKIRK†

If any person would ask ten different electronic manufacturers whose equipments cover a wide variety of electronic circuits for their opinions of electrolytic capacitors, it is possible there would be ten different answers. These answers might range from: "We use them all the time, and never have any trouble," to the extreme: "We wouldn't use them under any circumstance. They are not reliable."

Obviously, the first manufacturer has capacitor applications in which electrolytic capacitors operate satisfactorily. Also, the other manufacturer has no capacitor application in which electrolytic capacitors will operate satisfactorily and probably he has tried to use electrolytics with completely unsatisfactory results.

Which of these attitudes applies to electrolytic capacitors in computers?

You want to know whether electrolytic capacitors will operate reliably in computers or not. If they will, you want to know what procedure must be followed to insure reliable operation. Rather than to list specific applications in which electrolytic capacitors will operate reliably, it will be best to present the information by which a designer may determine in what applications and under what conditions electrolytic capacitors will give reliable operation.

Speaking of the reliability of components, there is no question that any component can be damaged by attempting to operate it under too severe conditions. Thus the point of deliberate misapplication need not be considered.

The first point to consider about the reliability of electrolytic capacitors is their theoretical reliability. If this is not good, there is no need to consider the problem beyond this point. Fortunately for the electrolytic capacitor industry, this theoretical reliability is excellent. The necessary elements of any capacitor, two conductors separated by a dielectric, are, in the electrolytic capacitor, materials with no inherent weaknesses. Also, the materials are such that if a flaw develops in the dielectric, the voltage applied to the capacitor will cause the flaw in the dielectric to be eliminated automatically. Another factor which indicates good theoretical reliability is that there are no moving parts in electrolytic capacitors.

Having determined that the theoretical reliability of electrolytic capacitors is excellent, the next step is to look at the practical side of the picture. Laboratory and field experience verify the conclusion of theoretically good reliability. Fig. 1 shows the electrical characteristics of an electrolytic capacitor after more than four and one-half years of accelerated laboratory life test operating at 65 degrees C. and rated voltage. All electrical characteristics are desirable. Capacity is greater than nominal, equivalent series resistance is less than nominal, and leakage is extremely low. These indicate excellent performance and reliability. As an example of exceptional reliability in the field, Fig. 2 shows an electrolytic capacitor which was manufactured in August, 1937. It is rated 12 mfd, 450 v dc. It was put in service in a new radio in September, 1937. It was the first filter capacitor in a capacitor input-filter circuit.

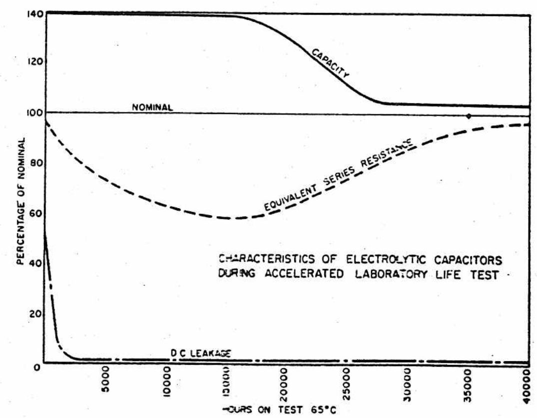

Fig. 1—Characteristics of electrolytic capacitors during accelerated laboratory life test.

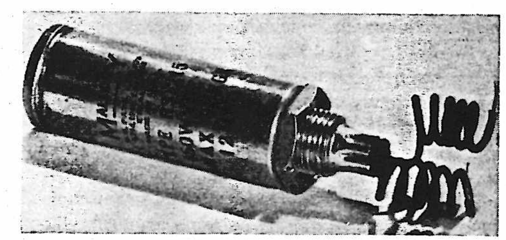

Fig. 2—Electrolytic capacitor after 16 years in service now tests as good as new.

Applied dc voltage was slightly less than rated. It was removed just a month ago even though it still was operating satisfactorily. The radio with this capacitor received a great deal of use for four and one-half years, then was put in storage for four years. When it was removed from storage, it was plugged into an electrical outlet, turned on, and it started to play within 30 seconds. Since then the radio, and the capacitor, have

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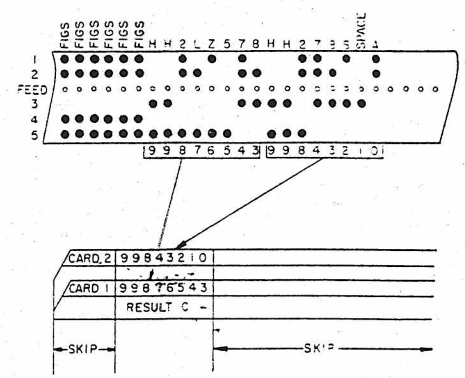

Figure 4 (left). Cards punched automatically on type 43 from a computer output tape

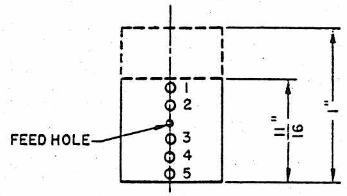

Figure 5 (right). Locations of information holes with respect to feed holes

tape if it is made on type *63* and, in fact, the machine will stop if a column on the tape is not punched with some code.

Fewer problems are encountered in preparing the output tape on the computer for subsequent conversion to cards on the type-*43* machine. The only requirement is that a series of FIGS codes be punched in the beginning of the tape to provide for proper automatic run-in operation. LTRS codes could be used provided a FIGS codes is punched immediately preceding the first digit code in the tape. One FIGS code at the beginning of the tape is all that is required since the machine will remain in figures case with no exceptions unless a LTRS code is read from the tape. It is, of course, entirely practical to precede each 8-digit number on the tape with a FIGS code. Actually it is possible manually to set the tape in position to read the first character, and since the type *43* is normally in figures case, no FIGS codes are necessary.

It may be desirable to allocate one column at the beginning of each number on the tape for algebraic sign. If this is done, the codes used for sign indication may be recorded to punch or not punch an *X* in any desired card column. Such an indication for signs could also be used as a means of checking by control panel wiring to insure that the card and tape are in step. Figure 4 illustrates a section of output tape and the cards that can be made from this tape. Conversion from binary to octal can, of course, be accomplished if the tape is punched in the form previously mentioned.

Tape Characteristics

The tape-punching mechanism of the type *63* is designed, as previously mentioned, to produce tape for use with telegraph equipment. The tape itself is an oil-impregnated paper, 11/16 inch in width and 0.0[illegible] inch in thickness. While the supply reel will accommodate a full roll of tape [illegible] inches in diameter (1,000 feet), the take-up reel will not. Figure 5 illustrates the relationship between the information holes in the tape and the feed holes. Further as indicated in Figure 5, it is possible by a simple adjustment of tape guide plates to feed tapes up to 1 inch in width through the punching mechanism. Only five tracks may be punched, however, and the location of the holes relative to the lower edge of the tape must be as shown in Figure 5.

In the author's opinion, the tape described is not entirely suitable for photoelectric reading because of its poor opacity. Presumably the type *63* can handle other kinds of paper tape but some laboratory testing would be required to determine definitely whether a particular tape is suitable.

Conclusion

In the applications just described, the objective was to indicate some of the potentialities and to point out the few limitations of the types-*43* and -*63* machines. While it may be bothersome, the limitations must be taken into account when it is decided to use the types-*43* and -*63* machines as connecting links between two systems utilizing different input-output mediums.

If, however, the associated problems are faced realistically, the machines discussed provide an economical, fast, and accurate means of interchanging information between punched-card calculating systems and machines utilizing perforated-tape input and output. Apart from the obvious advantages of linking two systems, there are two other advantages to be gained from use of the types *63* and *43*.

In manual preparation of input tapes the problem of correcting errors in the tape is always present. It is a considerably easier procedure to punch the data manually in cards, verify the cards, and, if errors are detected, repunch a few new cards. Such a procedure insures that the information ultimately recorded in a tape is error free.

Finally, another problem arises when it is necessary to make a copy of a tape and incorporate a few minor changes. This situation frequently occurs if a Teletype tape is used to control a machine's sequence of operations. It is an extremely laborious task to punch an entirely new program tape manually if only a few items are to be changed. Maintaining the program on a deck of cards is a highly practical solution to this problem, since modifying a program then requires changing only a few cards and punching a new tape automatically on the type *63*.

References

1. Principles of Operation—Type 63 Card-Controlled Tape Punch, Form Number 22-*5997-1*, International Business Machines Corporation, New York, N. Y.

2. Principles of Operation—Type 43 Tape-Controlled Card Punch. Form Number 22-*5691-1*, International Business Machines Corporation, New York, N. Y.

Discussion

Theodore Shapin, Jr. (University of Illinois): Our machinery interprets a sprocket hole only in the Teletype code as the decimal digit zero. How much of a modification would have to be made to your standard machines to handle this?

Mr. Nielsen: While this gets into the matter of company policy, I must admit it is a very minor modification. I suggest that you take your problem to your nearest IBM office where they can handle it directly.

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Devices for Transporting the Recording Mediums

R. L. SNYDER

THE large-scale digital computers now in use have demonstrated that efficient operation of their internal elements can be maintained in a manner satisfactory to the users. They have also shown great versatility in the problems to which they can be applied. As a result, a demand for such devices has been spread from among scientific laboratories through industry, commerce, and government, for their application to a myriad of purposes. In most cases, the requirements of the problems can be accommodated by any of the general-purpose machines and in many instances more specialized, less elaborate units can be used. Almost all installations require that a means be provided for keeping information in a latent form which can be recorded and reproduced by automatic mechanisms, under the control of the machine, for introducing input and absorbing output information, and for storing data too voluminous to be kept in the machine's high-speed internal memory.

Many factors enter into the choice of the latent information storage mediums and of the type of mechanisms used in manipulating it. The purpose for which the installation is used is, of course, of primary importance. This will determine whether high handling speeds are necessary in the input, output, or intermediate equipment. Usually, the input data are relatively small, so that speed at this point is not essential. The output data may only amount to a yes-or-no answer, in which case a simple indicator is all that is needed, but usually the output is very extensive and high speeds are needed. If intermediate storage is necessary, it is because the information in the problems is too abundant to be contained in the machine's internal memory. Therefore, it may be assumed that fast operation should be provided. Frequently, when intermediate storage of information is required, the same type of equipment and often the identical devices are used for all three functions. Occasionally, a computing system is used in an establishment where much of the data processed by the machine have been accumulated in the past and are kept in such a form that they can be automatically interpreted. In this circumstance, it may be advantageous to have an input device of a type which will accommodate existing records. A second input device which can handle a more desirable type of record may be included in the system and the first input unit discarded after the old records have been processed or transcribed.

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Other considerations determining the choice of record material and transport devices are the necessity for visual inspection of the records, the ability to reinscribe automatically an old record with new information, the type of computer to be served, the availability of devices already in use which may fulfill the requirement, and the time schedule which must be kept in completing the system, and, not the least important, the ingenuity of the designers.

In all designs, the method of handling latent information must be reliable and accurate. Reliability is necessary because frequent breakdowns cause lost computing time and require the provision of a greater number of maintenance people than would otherwise be needed. High frequency of failure also makes the maintenance of other parts of the system difficult. The degree of accuracy in operation required of these devices is such as to discourage a designer at the outset. If confusion of information occurs more often than once in 100,000 operations, the system will be practically useless. Satisfactory performance requires an error no more frequently than one in 10^6 to 10^7 operations.

Simplicity and convenience in operation are highly desirable to reduce the effort of mathematicians or other personnel using the system. It should be remembered that the efficiency of operation of an installation suffers as much if a computer is improperly operated for a day because of misunderstanding as it does if the machine is out of order for a day. Indeed, time wasted in this way is more costly than computer breakdown because it wastes the effort of the mathematicians and users as well as that of the technical personnel. Simplicity of operation is also desirable because the personnel, particularly where scientific computations are involved, usually changes frequently, and ease of instruction in itself saves time at the outset and enables an infrequent user to operate efficiently without instruction after a long absence.

Philosophy of Recording

In all systems of mechanized record keeping, wherein information is extracted from the recording mediums without human interpretation, it is recorded in a yes-or-no form. For example, if numbers are to be represented in decimal form, it is done by providing a particular character position with space for ten choices. Then to record, one of these spaces is marked or punched. The reading device then scans the position and finds that all but one of the choices are not marked and are therefore 'no,' the one choice which is marked indicating "yes." This system is common among card-handling devices where each position is provided with a column of characters ranging from zero to nine, and a hole is punched through one of the characters. Such a system provides a record that is easily interpreted by humans, but is somewhat wasteful of recording space and time.

Most efficient use of the recording medium can be made if the less familiar binary notation is used. In this system,

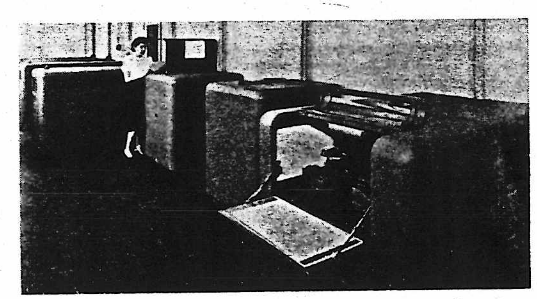


Figure 1. Perforated tape-handling devices used for input, output, and intermediate storage by the Bell relay computer, Aberdeen Proving Ground

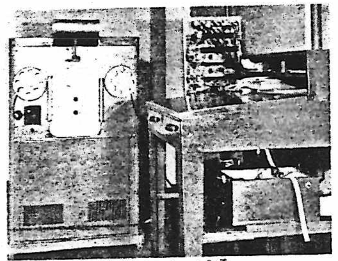


Figure 2. High-speed photoelectric tape reader and telegraph perforator used with EDVAC at Aberdeen Proving Ground

the numbers are the summation of combinations of different powers of two, whereas decimal numbers are the summation of constants, each of which is multiplied by a different power of ten. Binary notation, therefore, requires, only an indication as to whether or not a particular power of two or digit-position is to be counted in the summation. An example of the convenience of binary notation is found in the magnetic recording of digital information on wire. The information is stored in adjacent segments of the wire which form very small permanent magnets whose poles are displaced from one another longitudinally. Each elemental magnet following a characteristic marker, designating the beginning of a word (usually an unmagnetized section of the wire), represents a power of two or digit-position in the number. Whether or not a digit is to be counted in the summation is determined by the order in which the poles occur. If north precedes south, the element may represent one and if south precedes north, the element then represents a zero.

The relative efficiency of use of storage space of the binary notation over decimal notation used in mechanized record-keeping devices can be demonstrated by comparing the number of choice spaces required to hold a number which can have any one of a thousand values. A decimal number will require three sets of ten choice spaces, whereas a binary number with a slightly greater range of values can be accommodated in ten spaces.

The simplicity and efficiency of binary notation is, however, offset to a considerable degree by its unfamiliarity and an inherent occular difficulty in reading of binary numbers by humans. Furthermore, the mechanization of conversion of decimal notation to binary, and conversely, requires arithmetic operations which involve expensive equipment, if a converter is used, or appreciable computing time and memory space in the computer if the conversion is carried out by a program in the computer.

There are, however, several kinds of notations which effect a compromise between the two extremes of efficiency and ease of interpretation. These can be exemplified by a discussion of binary coded decimal notation. It may be mentioned that a choice of two combinations can be had from one binary yes-or-no element, sometimes called a bit, four combinations from two such elements, eight from three, and 16 from four bits. Therefore, a decimal character having only ten possible values can be represented by four binary digits. So, to store any one of a thousand combinations, this system would require 12 elements. Although this notation is not as easy for humans to read as decimal numbers, it is much less difficult than is binary. Conversion between decimal and binary coded decimal information is quite easy technically, requiring only a simple matrix device. These systems are used extensively with tape records. For example, paper tapes may be arranged to have holes perforated in rows which are perpendicular to the length of the tape.

Figure 4. Card and tabulating equipment associated with ENIAC at Aberdeen Proving Ground

The holes are made by a group of four or more electrically driven punches operating in concert so that all of the information in each row is punched and may be read simultaneously. Such records are not difficult to interpret visually because each character lies in one position along the length of the tape.

It should be noted that most tapes accommodate more than four holes because most perforated-tape-handling equipment has been designed for communication service in which it is necessary to process alphameric information. Usually, if only numbers are to be recorded, such spare hole spaces are used for redundant checking. This is done when five hole spaces are available by punching the fifth space if, and only if, an even number of holes is

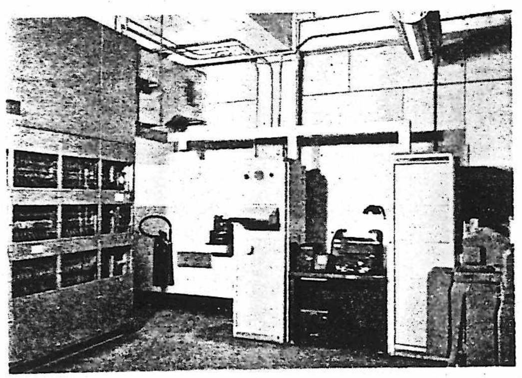


Figure 3 (left). ORDVAC with perforated tape-handling device in central background, and card-handling equipment at extreme right

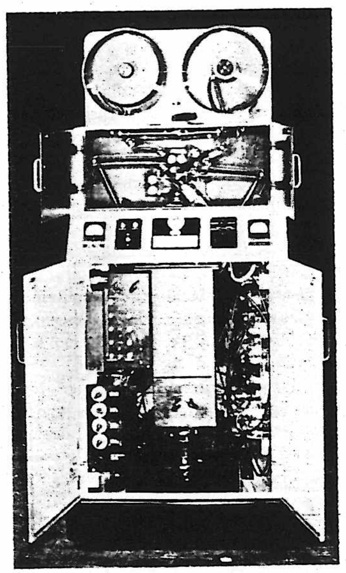
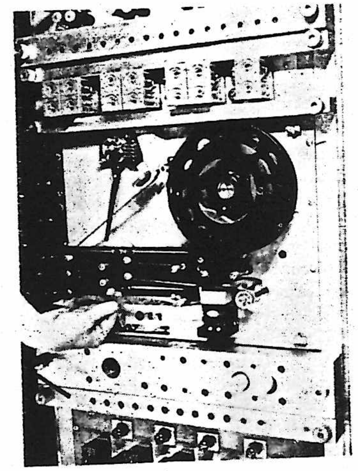


Figure 5 (right). Photographic input and output device

Courtesy Eastman Kodak Company



Courtesy Raytheon Manufacturing Company

Figure 6 (left). Bidirectional magnetic tape transport with photosensitive elements for scanning visible address marker on back of tape

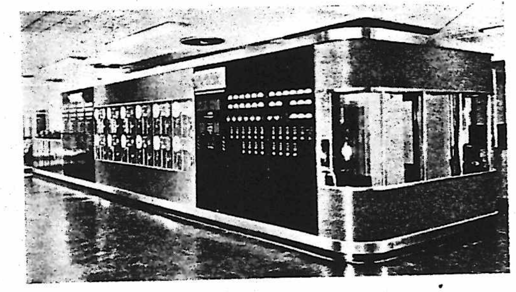


Figure 8 (right). Tape transports using vacuum adhesion to move and stop tape installed on Mark IV computer at computation laboratory of Harvard University

present in the four binary coded decimal spaces. When such a symbol is later read from the tape, a special circuit indicates an error if there is not an odd number of holes. Usually, there is also a circuit which will produce an error alarm if the binary value of a character is outside the decimal range.

In addition, a count may be made to ensure that each word or group of symbols has the correct number of characters. In some instances, particularly when magnetic tape is used as the recording medium the complement as well as the number is recorded and must be correctly reproduced, otherwise an error halt is effected. It has been proposed that triple recording be used and the system arranged to accept a number if two of the three records agree, so that fewer error halts will be experienced.

The method and degree of checking are of considerable importance in the design of latent-information-handling devices because the equipment, information storage capacity, time of operation, and maintenance requirements are all increased by these measures. These considerations are of particular moment in the development of magnetic-tape equipment because the reliability of these systems decreases with increases in the density of recording. So much checking may be required by dense recording that even more tape will be needed for closely packed information than for more conservative signal spacing.

The two exceptions to the use of yes-or-no notation in recording computer information are in the keyboarding or preparation of input information and the presentation of the printed output. In keyboarding, conventional symbols are present on the keyboard for the operator to see. The depression of a key causes a binary coded symbol corresponding to the character to be registered on the input medium. In the printing operation, ordinary symbols are recorded on paper by some form of automatic typewriter. Such devices are controlled from yes-or-no binary coded signals, either directly from the computer or from transcribing equipment extracting information from the recording medium used in the other operations described.

To provide a clearer understanding of how the principles discussed in the foregoing may be applied, some examples of each of those now in use are presented in the following.

Perforated Tapes

Perforated tapes have long been used by the telegraph systems for storing alphameric information relating to commerce and finance at relay points in their systems. The advanced development of mechanisms for perforating and reading tape and the availability of tape-handling equipment caused its adaptation to computer use. Tape is easily handled mechanically, can be interpreted visually, and can be rapidly scanned by photoelectric devices. Unfortunately, recording by punching is very slow, standard telegraph punches are capable of perforating only a few characters per second. Some work is being carried on to develop high-speed punches, but at present the equipment available is entirely inadequate for electronic computers.

One of the first installations to use perforated tape is the Bell relay computer at Aberdeen Proving Ground, Md. Figure 1 shows the input-output and tape-processing equipment associated with this computer. Input tapes are prepared on keyboarding equipment which produces a typed copy for easy checking. These tapes, along with tape on which are re-

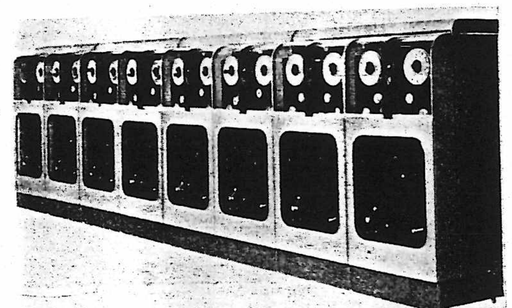


Figure 7 (left). Automatic magnetic tape transports. Medium is plated metallic ribbon

Courtesy Eckert-Mauchly Division of Remington Rand Inc.

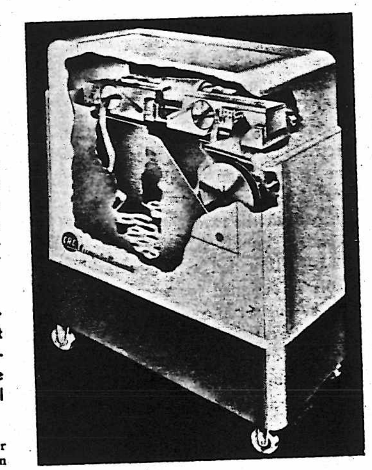


Figure 9 (right). Commercial tape transport using oppositely rotating capstans and squeeze rollers for bidirectional acceleration

Courtesy Computer Research Corporation

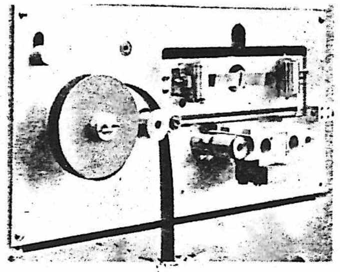


Figure 10.- Mechanism of squeeze roller tape transport, Aberdeen Proving Ground

coded standard routines, are placed at their starting points in the mechanical tape reader. The mechanism then advances the tape automatically on instructions from the computing system. Output punches also automatically advance new tape from reels as needed. The tape used is a special 6-hole Teletype tape which is recorded in a biquinary code and provides redundancy for self-checking. The computer is a relay machine, so that the comparatively slow speed of about two characters per second in the tape equipment complements the deliberate pace of the calculations. This system is exceedingly reliable: few errors occur other than those caused by key punching and practically all errors are immediately detected and cause the machine to halt. The recording is performed by low-speed punches and the reading by mechanical feelers actuating contacts.

Several other perforated-tape installations have been made in high-speed computing systems. Among these are the SEAC at the National Bureau of Standards, the computer at the Institute for Advanced Study, the Ordvac built at the University of Illinois, and the Edvac recently completed at Aberdeen Proving Ground. Figure 2 shows the Edvac installation with a Western Union tape punch on the desk shelf at the lower right of the illustration, a standard telegraphic unit, and a high-speed photoelectric tape reader in the background. The former can produce about four characters per second, whereas the latter can read at the rate of 1,200 symbols per second. The punch is automatic once it has been threaded with new tape. The reader is designed for automatic operation, having servo-controlled reels and an automatic capstan; however, it is seldom used with automatic control because it is easier to pull the tape by hand than to set up the reels. The internal memory is sufficiently large to hold an extensive program and the speed of the reader is so great that the time for pulling the tape is negligible. These shortcomings are noted because they emphasize the necessity for simplicity of operation. A tape transport mechanism which is much easier to use is shown in Figure 10. The serious unbalance of the speeds between the input and output of this system and others like it has brought about programs for the development of better recording devices.

Punched Cards

One of the means employed to obtain greater output speeds has been the installation of standard card-handling equipment. In these installations, information can be handled at rates of about 100 characters per second. These speeds are obtained by using many relatively slow electromechanical punches to perforate each card. One standard commercial card punch uses cards accommodating 80 characters perforated by 80 separate punches. This speed can be, in effect, increased by clever manipulation of the logic relating to the arrangements of the perforation patterns. Figure 3 is a picture of the Ordvac at the Ballistic Research Laboratories at Aberdeen where the original perforated-tape equipment is shown in the central background and the card-handling devices manufactured by the International Business Machines Corporation at the extreme right. The computer is shown to the left. In this installation, the perforated information patterns in the cards are made to correspond to a similar pattern in the high-speed internal electrostatic memory, so that the meaning of the patterns can be made to conform to any logic desired. At this writing, each card is used to store 24 40-binary-digit words, wherein each word is equivalent to about 12 decimal characters. The card-handling devices operate at the speed of about 80 to 100 cards per minute so that the system is capable of transferring the equivalent of approximately 400 decimal characters per second. Cards which have been keyboarded to record input information and cards which have subroutines which may have been generated by the computer, are assembled in stacks which are placed in the reader. New cards are stacked in a hopper in the punch to receive output or intermediate information. The output cards are then run through a tabulating machine for final printing. These devices cannot be reversed to permit searching for information as can the tape equipment.

Figure 4 shows the older installation of the card-handling equipment in the Eniac system at Aberdeen Proving Ground. This is somewhat slower because the cards are used with the standard commercial notation. The card systems are very satisfactory because long development and years of experience have brought about great reliability in card mechanisms and in tabulation equipment. Furthermore, the information is at all times easily re-arranged to fit into various routines.

Photographic Recording

Another means of automatically handling information in a way that can be visually interpreted and at the same time handled automatically at high speeds involves photographic processes. Such a system developed at Eastman Kodak Company for "Project Whirlwind" is shown in Figure 5. This equipment uses motion picture film which is automatically exposed to patterns on the face of a cathode-ray tube for recording, and which is scanned photoelectrically for reproduction. The information is recorded in a redundant binary code which provides facilities for checking. The patterns consist of rows of dots which represent binary numbers and their complements. About 2,500 bits per square inch are accommodated. Several of these mechanisms have been made and, in themselves, performed satisfactorily. However, the time and the difficulties involved in the development of the film, and the high cost of the medium, have made it appear likely that they will not be widely used in the near future for handling coded information. Nevertheless, it appears that the development of film-handling equipment is necessary to produce mechanisms which will be required to handle information that must be stored in pictorial form.

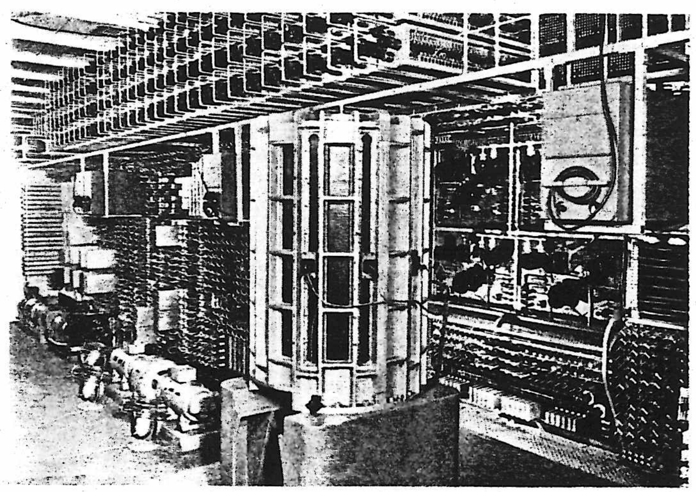


Figure 11. A magnetic memory drum associated with Mark IV computer, Harvard University

Magnetic Tapes

From the standpoint of mechanization, probably the most versatile means of storing latent information for computers is that involving magnetic recording and reproduction. In devices of this type, the surface of the storage medium, which is composed of magnetizable material, is placed near to, or in contact with, a small electromagnet called a head, which may be energized by a pulse of electric current that causes a strong magnetic field to pass in and out of an elemental area of the magnetic surface so that this area thereafter remains magnetized. The magnetized area may then be transported to some other place for storage and can later be brought under the poles of the head where the motion of the magnetized area past the poles causes a slight amount of flux to build up and subside in the core structure of the head and generate a voltage across its coil. The polarity of the field from the magnetic region is determined by the direction of the current in the recording head which is so chosen that in one direction it will represent a binary one, and in the other direction a binary zero. Usually, the poles are arranged on the magnetic surface in such a way that they succeed one another in the direction of motion, in which case the recording is said to be longitudinal. They may be oriented at right angles to the direction of travel, in which case the recording is said to be transverse. In some instances, where thin magnetic recording mediums are employed, magnetization is through the medium with a pole on either side of the record. Magnetic records can be made extremely rapidly. A good recording can be made by a pulse the duration of which is less than a microsecond. The magnetized regions can be exceedingly small. In contact recording, some areas are of the order of 0.01 inch wide and 0.005 inch long. With such high densities of information, very conservative mechanical speeds can be used to transfer information rapidly enough to fulfill all the requirements of electronic devices. Magnetic records may be reproduced a very large number of times without destruction, will last indefinitely, and may, in many types of equipment, be modified with no more trouble than the simple operation of recording over the previous record. In some instances, erasure by high-frequency magnetic fields may be required before a new record can be superimposed over an old one.

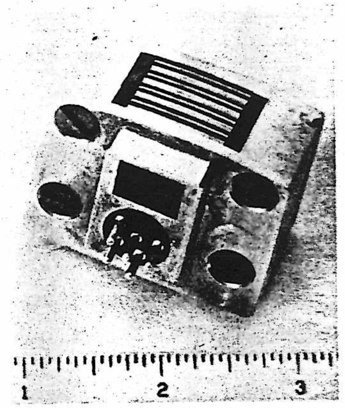
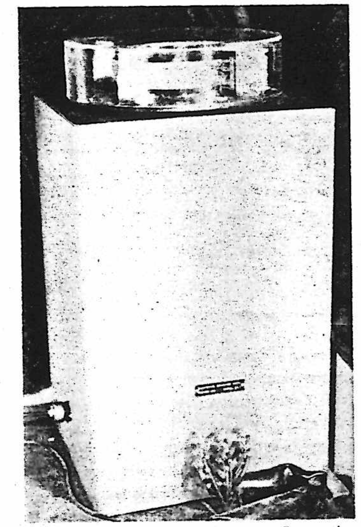


Figure 12. Magnetic head assembly for Mark IV drum, Harvard University

One of the most commonly used kinds of magnetic record is made on flexible tape having a ferromagnetic surface. Usually the magnetization is longitudinal and the tape is run in contact with the recording and reproducing heads. The density of recording on tape varies over wide limits. In a longitudinal direction, it ranges from 25 to 400 per inch and in a transverse direction from 4 to 32 tracks per inch.

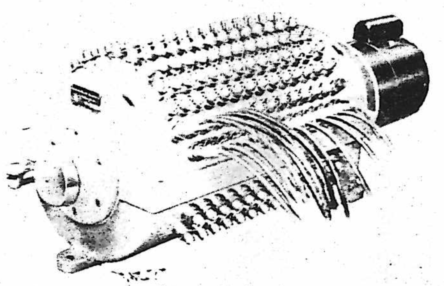
In Figure 6 is shown a magnetic tape drive developed by the Raytheon Manufacturing Company and used in a number of installations. The unit in the illustration is installed in the Raydac.



Courtesy Electronic Computer Corporation

Figure 13. Small commercial drum

This tape carries six channels, is equipped with bidirectional servos, and has the unique feature of having visible photoelectrically read address markers on the back of the tape to facilitate rapid search operations. Also to be noted is the rather elaborate tape-tensioning system. The density of recording is not standard on these units, being chosen to fit the particular installation. Another commercially available tape transport system is shown in Figure 7. This unit is called the Uniservo and is manufactured by the Eckert-Mauchly division of the Remington Rand Corporation. It employs metallic tapes with multiple channel recording. The picture shows a battery of eight units. Figure 8 shows the magnetic tape installation on the Mark IV computer built at the computation laboratory at Harvard University. These transports utilize a very fast vacuum-type accelerator and brake. Another commercial unit is shown in Figure 9 which is made by the Computer Research Corporation and utilizes a principle developed at the National Bureau of Standards. This principle is better illustrated in Figure 10, which shows a similar device built at Aberdeen Proving Ground to handle both magnetic and perforated tapes. In this transport mechanism, tape is laid in a slot under which are placed magnetic heads or photoelectric cells, depending on the type of tape to be used. The cover carries two magnetically moved idler rolls and when it is closed, the tape lies between the idlers and two capstans which rotate in



Courtesy Engineering Research Associates

Figure 14 (left). Drum using non-return-to-zero recording

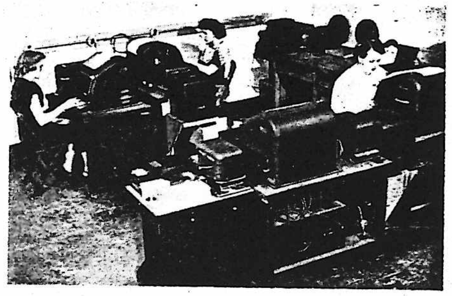


Figure 16 (right). Teleprinters used to process output of EDVAC and ORDVAC at Aberdeen Proving Ground

opposite directions. The tape is then drawn from the reel by manually controlled electrically driven rollers into a basketlike receptacle. The tape can be moved in either direction by actuation of one idler roll magnet which causes the tape to be squeezed between the actuated roll and one capstan. This action causes the tape to be pulled toward the actuated side. Braking is constantly applied by a spring-loaded shoe.

It may be noted that in all magnetic-tape transport mechanisms considerable effort has been made to achieve rapid acceleration and deceleration. This characteristic is necessary because the amplitude of the signal generated in the output system is proportional to the speed with which the elemental magnets pass the reading head. Slow starting and stopping cause the first few and the last few characters to be so poorly read that their information is unreliable. This condition is particularly important when the space between words is very small.

Magnetic tape, as the medium of recording of digital information, is very attractive because the recording and the reproducing speeds may be as great or as small as desired; bidirectional operation can be provided; many tracks may be used; and the information can be erased and recorded without difficulty. Though the users of magnetic tape have found many serious difficulties they have, it is pleasant to state, to a great extent surmounted them. Outstanding among these have been the difficulties caused by particles of foreign matter which lift the tape from the head at a critical instant, irregularities in magnetic and physical properties of the tape, and in making the tape track through the guides and rollers.

Wire

In an effort to achieve a denser storage of information, and possibly alleviate some of the dust and irregularity troubles encountered with tape, the National Bureau of Standards and the Institute for Advanced Study have conducted research to produce magnetized-wire-handling equipment. To date, such a system has not been satisfactorily used. It is also beset with mechanical difficulties, the principal one being that of manipulating the wire so that no snarls or kinks result. The trend seems to be toward using wire held in special capsules from which it is never removed except for a very short section that passes between rolls in the capsules to contact the head.

Drums

Probably the most successful magnetic recording devices so far used in conjunction with computing machines are rotating drums. Unfortunately these devices can only be used for intermediate storage because the medium of recording is the surface of a heavy cylinder which turns in precise bearings and, therefore, cannot be removed from the equipment and placed in a filing cabinet. The capacity of such drums varies from 500,000 to about 3,000,000 bits of binary information. The surface of the drum is coated with magnetic material and exposed to heads which record circumferential tracks that are displaced in an axial direction from one another by their own widths plus a slight space necessary to provide sufficient isolation to prevent crosstalk. The heads clear the surface of the drum by about 0.002 inch. The density of recording along the circumference of the drum may lie between 10 and 150 bits per inch. The speed of rotation of the drum ranges from 1,200 to 7,200 rpm.

A typical installation is shown in Figure 11 which is the drum associated with the Mark IV computer at Harvard University. A head assembly for this drum is shown in Figure 12. A small commercially available drum made by the Electronic Computer Corporation is shown in Figure 13. Another commercially built drum which was manufactured by Engineering Research Associates is shown in Figure 14. This company records on its drum in what is called a nonreturn-to-zero system. In this type of recording, only the changes in the polarity of the bits are noted; that is, only those signals are used which are generated when a binary digit is succeeded by another binary digit of opposite sign. This type of recording is advantageous because it has been found that the signal developed in this fashion is much greater and less ambiguous than those reproduced from conventional pulse recordings where each pulse is resolved in the output circuits. This system requires slightly more complex circuits to reproduce the signal, but by its use the storage capacity of the drum is considerably increased.

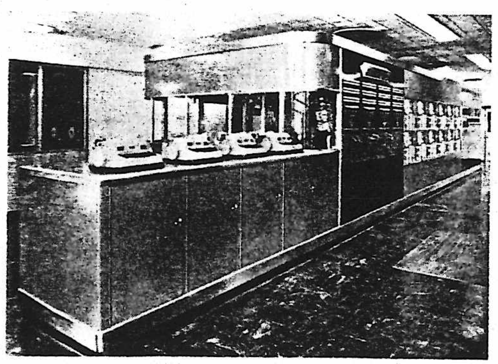


Figure 15 (left). Mark IV automatic electric typewriter at Harvard University

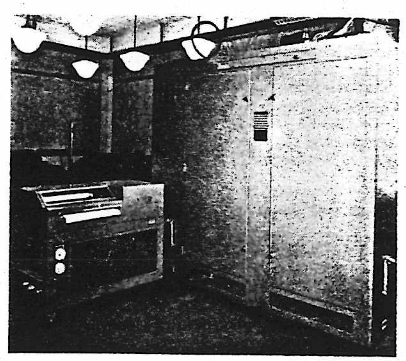


Figure 17 (right). Shepard high-speed printer at Aberdeen Proving Ground

Preparation Devices

Most of the manually encoded data for large-scale computers are prepared on standard tape- or card-punching keyboards, modified only to the extent necessary to provide the symbols peculiar to the particular work. Such equipment has long been available and little improvement can be desired because this is the one instance in which all of the speed requirements have been fulfilled.

Printing Devices

The output of computing machines, which must be in a form to be read by humans, is generally presented by automatic typewriters. These typewriters may be controlled by the computer directly or by transcribing equipment which interprets information from the computer's input-output medium. The transcribing procedure is more commonly used because most of the automatic typewriters are so slow that valuable computing time would be wasted if the machine had to be stopped while the printers performed their tasks. Figure 15 shows the electric typewriter complement for Mark IV.

An installation using the conventional Teleprinters at Aberdeen Proying Ground is shown in Figure 16. Also shown is equipment used to prepare perforated tapes. A more advanced development is shown to the left in Figure 17. It is a very-high-speed rotary printer manufactured, by Shepard Laboratories for Aberdeen. This is one of the class of printers which are also made in different designs by Potter Instrument Company and Wheaton Engineering Corporation. In it a number of sets of all of the characters to be used are arranged around the circumference of a rotor. Directly beneath the rotor is a typewriter ribbon underneath which is the paper from a roll on which the printing is to be done. Beneath the paper is a row of electrically operated hammers. The drum rotates at some speed between 5 to 30 revolutions per second. The hammers are then energized by a decoding apparatus at such a time that they will strike the paper against the inked ribbon and the rotor when the desired character is in the proper position. Such a printer is fast enough to keep pace with the fastest computer and no intermediate storage is needed to conserve time.

Conclusion

At the moment of writing, it appears that magnetic recording devices are the most flexible units for handling the mediums used for manipulation of latent digital information. However, the mechanical difficulties which now beset their use indicate that much more research and development will be necessary before completely satisfactory systems are available. For certain applications, perforated cards and tapes will probably be more satisfactory than any other medium, particularly where the amount of data to be handled is small, visual inspection is desirable, and redundancy is to be avoided. Photographic storage of pictorial information, and possibly printed output matter, needs considerable development but will undoubtedly perform valuable functions which cannot be otherwise accomplished. Simpler and less expensive automatic printers must be developed. When it is remembered that serious work on these devices commenced little more than 5 years ago, the progress in their development must certainly be the source of considerable satisfaction to those working in this field.

Discussion

L. Difford (National Bureau of Standards): Will you please give more detail on the Shepard printer?

Mr. Snyder: I shall describe it as completely as I can. The print roll consists of a cylinder about 16 inches long, having 56 character wheels on it. It has a typewriter ribbon, about an inch wide and slightly skewed, underneath the roll and clearing it by some 0.005 to 0.01 inch. The paper, I believe, is about 16 inches wide. There is a row of hammers aligned beneath the paper at intervals of about 3/16 inch. The printing does not extend over the full width of the paper.

The time of flight of a hammer striking the paper appears to be about 2.7 milliseconds, and the dwell time has been guessed at as being about 8 microseconds. The hammers are actuated by thyratrons.

Mr. Difford: You said 15 lines per second. Is there any way of speeding this up?

Mr. Snyder: That is most conservative, because the print roll is rotating at 30 revolutions per second, and one revolution is assumed to be allowed for paper shift. Actually, a quarter of a revolution is sufficient, and these printers have been operated with 60 revolutions per second. The problem appears to be one of moving the paper rapidly rather than of getting the hammers to strike accurately.

W. P. Byrnes (Teletype Corporation): What is the maximum number of channels or rows across the width of the tape envisaged at the time for either magnetic or perforated tape?

Mr. Snyder: That is a very hard question to answer. I have heard of some magnetic tapes as wide as 6 inches, involving something like 30–50 tracks. I have also seen some installations where there is a single track on magnetic tape 1/4 inch wide. In the perforated tapes, the standard 5-hole Teletype tape is, of course, quite useful. The 6-hole tape was used in the relay type of computers, but some tapes, if one may call them that, have been as wide as the standard punched card, that is, 80-column tapes. I believe they have been used in the selective sequence calculator at the International Business Machines Corporation in New York City. I do not think there is any limit in either case, except for magnetic tapes, where the dust problem may cause serious difficulty.

Mr. Byrnes: In some cases, it may be desirable to represent more than one decimal digit across the roll of tape.

Mr. Snyder: It may also be desirable for checking.

Mr. Byrnes: What speed of reading and perforating paper tape is considered adequate at present?

Mr. Snyder: At present, the best perforation speed that I happen to be aware of is in the Ordvac card-punching system, which punches the equivalent of about 400 characters per second. I think that is more rapid than is absolutely necessary for a device to be very useful to the computing industry. I think, from 100 characters per second up would be very useful for many applications.

Mr. Byrnes: That also goes for reading tape?

Mr. Snyder: Yes, but reading perforated tape is easy with photoelectric devices—perhaps not easy, but it is quite amenable to a little effort, shall we say? There is no limitation to reading photoelectrically.

Mr. Byrnes: Is it true that reading mechanically requires less associated equipment?

Mr. Snyder: I think that was true some time ago, but with the introduction of

transistor photoelectric cells, the output is sufficient to drive almost any kind of equipment. For any other kind of electric device it is necessary to provide some coupling network. I do not think you gain appreciably in the signal level by just using contacts driven by mechanical feelers. Certainly, one amplifier tube is cheaper than a set of contacts for maintenance. If you use some of the gray tapes and photomultipliers, you can get enough light through without any difficulty, even with paper tape.

Mr. Byrnes: Would you repeat the name of the company that puts out this line-at-a-time printer of which you spoke?

Mr. Snyder: The Shepard Laboratories at Summit, N. J.

M. M. Astrahan (International Business Machines Corporation): Do you know where this transistor photoelectric cell is being used?

Mr. Snyder: It is used on the Aberdeen tape reader, which I described in some detail.

Mr. Astrahan: Is it in operation?

Mr. Snyder: Yes, but they are having trouble getting enough of the transistors; the transistors are apparently going to become available, if the grapevine information I have had is true.

B. Lippel (Signal Corps Engineering Laboratories): Photographic means have been described for rapid printers. Would you care to comment?

Mr. Snyder: There is a type that was described by Engineering Research Associates. There are a great number of printing devices that use photographic reproduction, some that are derived from cathode-ray tubes whose deflection is controlled to write actual letters, and some that are controlled by masks, and I believe a few by monoscopes. I believe for writing legible decimal and alphabetic characters, photographed cathode-ray images will certainly be the fastest system that can be employed because such recording can be done quite easily at the rate of a character per microsecond. However, very few of the present large-scale computers can hope to keep up with such a scheme; in fact, none of them come anywhere near such speeds. The development problem, I think, is one that needs a little more work before such devices will be acceptable.

Mr. Astrahan: I think the cathode-ray output on Whirlwind is sometimes used. Photographs are taken of the screen, and various characters and other displays are obtained that way. It is not a high-speed device, but they get some interesting figures on it.

R. F. Johnson (University of Toronto): Could you say anything about the availability of electrosensitive paper for printers?

Mr. Snyder: I have not had any experience with them or talked with anyone, other than to have heard of the use of Teledeltos papers in place of perforated tapes to produce a rather quick recording and a photoelectrically readable record. The actual printing of characters I have not seen, nor have I read of its being carried out. It seems to me a neglected field.

K. M. Rehler (Raytheon Manufacturing Company): On that roller type similar to SEAC units, what is the acceleration time and tape distance, and the maximum speed?

Mr. Snyder: In the unit shown, the tape runs at 8 feet a second, it stops in about 0.030 inch, I believe. The starting distance is about the same.

Mr. Rehler: Would that take the normal width?

Mr. Snyder: The unit, an experimental model, is designed so that the paper channel can be varied in width up to 1 inch. There is space under it for placing either photoelectric or magnetic pickup devices.

W. H. Ware (Rand Corporation): Mr. Snyder has stated that he does not know of any output equipment which utilized Teledeltos paper, and that he considers this an overlooked possibility. I should like to contribute the following information.

In June, 1951, there was completed at the Institute for Advanced Study, Princeton, N. J., a high-speed printer utilizing Teledeltos paper. The intended use of this device was to print rapidly, in binary notation, the contents of the internal memory, either for initial checking or for monitoring the progress of a problem. The 1,024 words of the memory were to be displayed 2 to the line, 40 columns in each word. It subsequently evolved that this moving stylus Teledeltos printer could also be used to construct curves or bar graphs; and even, if the data within the internal memory were first operated on by a suitable interpretive code, to print decimal characters.

This device is based on a Western Union 3-stylus Telefax machine, originally intended for remote delivery of telegrams. As modified mechanically and associated with suitable electronics, the printer is capable of printing, on standard $8^1/_2$-inch paper roll, 80 columns of binary information (either mark or not) with suitable center and edge margins. It produces 1,000 lines per minute and hence 80,000 bits per minute are printed. Provision is made to print each line of data more than one time (a maximum of eight) in order to give immunity against statistical flcutuations in the behavior of the paper.[1]

REFERENCE

1. A TELEDELTOS OUTSCRIBER, W. H. Ware. *Transactions*, Institute of Radio Engineers (New York, N. Y.), number PGI—1, April 1953.

Buffering Between Input-Output and the Computer

A. L. LEINER

THIS paper will discuss some of the basic methods or general principles which have been applied for carrying out the transfer of words between input-output equipment and the high-speed memory of computers. Since general principles can best be demonstrated by showing them exemplified in particular cases, specific selected systems which accomplish this buffering will be discussed. (In doing so, however, an attempt will be made to avoid detailed descriptions of specific pieces of equipment.) The particular selection chosen represents, of necessity, a quite incomplete sample from the total of available methods. Omission of some of the many alternative methods for accomplishing similar objectives in no way implies that the methods omitted are inferior to the methods presented.

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Nature of the Buffering Problem

Before proceeding further, it will be well to consider for a moment the special nature of the relationship between the internal circuitry of present-day high-speed digital computers and the external input-output equipment through which they communicate with the outside world. The first and most obvious difference between these unequal partners is the much slower operating rates of the external input-output equipment, but the main distinction between the two is the fact that the external devices (whether high-speed magnetic recording equipment or mechanical typewriters) are bound by mechanical inertia or friction

and therefore in most cases are incapable of following in rigorous synchronism with the high-speed internal electronic circuitry. On this account, the input-output equipment does not communicate directly with the high-speed units of the computer but rather with special buffering equipment which in turn communicates with the high-speed memory. This buffering equipment, since it is in direct communication with the memory, must be capable of operating at the same rate as the memory and its associated computing units. Efficiency generally suggests, therefore, that such equipment be constructed out of the same basic electronic building blocks as the regular computing units. In the following discussion this is assumed to be the case, not only for whatever special buffer word storage is needed, but also for the circuitry communicating directly with the slower moving nonsynchronous outside world.

Subdivision of Buffering Process

The process of buffering between an external input and the computer may be divided into three distinct phases. The first phase consists of the conversion of a nonsynchronous pulse signal (generally of irregular repetition frequency and uncertain duration) into a unique pulse signal, synchronous with, and of a shape acceptable to, the high-speed internal switching circuitry of the computer. The source of the external input signal may range all the way from a push-button switch contact up to the output of an amplifier of a magnetic recording unit capable of transmitting pulse code at the rate of many thousands of binary digits per second. In the first step of the input process, we carry through to the point where an individual binary digit is stored inside the computer in the form generally used for storing individual binary digits elsewhere throughout the computing system (for example, flip-flop storage). In the second phase of the input process, the assembly of successive binary digits into complete words is considered. This part of the process generally involves the counting of digits as they are received, the shifting of previously received digits into new storage locations in order to make room for subsequent digits, and the dispatch of signals indicating that a complete word or block of words is ready for transmission further along towards the high-speed memory of the computer. In the third phase of the process the procedure is considered for transporting such completed words from these temporary buffer storage locations to their final locations in the high-speed memory. This part of the process generally involves the counting of completed words or blocks of words, keeping track of the high-speed memory addresses into which successive words are to be transferred, and other related considerations.

The output process, in which information is transferred from the high-speed memory to the external unit, involves nearly exactly the same procedures, carried out in reverse order. For those aspects of the processes which have already been mentioned, identical equipment can be used in carrying out both the input and the output operation. The distinction between the two operations lies mainly in the terminal magnetic reading-recording equipment, keyboard printers, and so forth.

The following discussion will show how these three phases of the buffering process can be carried out by special types of buffering equipment, such as pulse-synchronizing systems, specialized storage registers, and associated control mechanisms.

Properties of Circuitry

The subsequent discussion will be confined to buffering systems which can be constructed out of internal circuitry possessing the following characteristics:

1. The entire computer operates in synchronism under control of a central clock.

2. One of the elementary basic building blocks is a signal-generating unit which provides (under control of the central clock) reshaped, retimed, standard output signals whenever suitably triggered. Signals of either positive or negative polarity are available from these units.

3. Another elementary block is the coincidence gate (AND-gate) which transmits a signal from its output only when every one of its inputs receives positive signals in unison. The presence of a negative signal is interpreted in the same way as the absence of a positive signal, and conversely. A single negative signal can thus be made to inhibit all output from such a gate.

4. Another elementary block is the mixer (OR-gate), which transmits a signal from its output whenever one or more of its inputs receives a signal.

5. Another elementary block is the electrical delay line (or equivalent) capable of delaying incoming signals up to several pulse repetition times.

These qualifications do not restrict the generality of the discussion, since both serial and parallel computing systems can be constructed out of the elementary blocks described. Because more variety in the choice of methods for buffering is possible in serial than in parallel systems, more examples of the former will be described.

Pulse Synchronization

FUNCTION OF PULSE SYNCHRONIZER

The most critical link between the internal and external equipment, bridging the gap between the slow outside world and the high-speed internal circuitry of the computer, is the pulse-synchronizing unit. This unit accomplishes the first phase of the buffering process, which is the conversion of a nonsynchronous signal to a synchronous one.

The pulse-synchronizing circuitry receives from outside of the machine an input signal which is both unsynchronized (with respect to the internal clock's pulse repetition rate) and nonstandard (with respect to the internal circuitry's pulse shape and duration). It is the function of the pulse synchronizer to derive from this input signal new internal signals possessing the following characteristics: First, the new internal signals must consist of standard-shaped pulses of a sort acceptable to the internal high-speed switching circuitry of the machine and, second, there must be an exact one-to-one correspondence in meaning between the signals received from the outside and the pulses transmitted to the computer. This correspondence must persist even though the external triggering signal might long outlast the triggered internal pulse. For example, a signal from a relay contact lasting 100 milliseconds must result in only a single pulse of 1-microsecond duration, not 100,000 such pulses.

To accomplish these functions, a pulse-synchronizing system of the type under discussion must possess the following abilities:

1. It must be capable of detecting an incoming signal at any nonsynchronous time and of storing it for an arbitrary period pending the occurrence of the internal synchronous timing pulse which transmits the news of the signal's arrival into the internal circuitry of the computer.

2. It must always transmit to the computer only pulses of standard time width. In doing so, it must contend with the fact that the partial overlap of a synchronized pulse and a nonsynchronized pulse (such as the coincidence of the leading edge of even a very long nonsynchronous input with the trailing edge of a standard internal timing pulse) tends to introduce substandard-width 'spikes' or 'slivers' into the system. Since as many as 10^{10} pulses per day are to be handled, the absence of even highly improbable time coincidences capable of causing malfunctions of this sort cannot be left to chance.